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CALCULATION TITLE PAGE

CALCULATION NO. NED-P-MSD-086 PAGE NO.: 1

☐ SAFETY RELATED ☐ REGULATORY RELATED ☒ NON-SAFETY RELATED

CALCULATION TITLE: LaSalle Station Steam Tunnel Main Steam Line Leak Rate Calculation

STATION/UNIT: LaSalle Station/U1& U2 SYSTEM ABREVIATION: MS

EQUIPMENT NO.: (IF APPL.) PROJECT NO.: (IF APPL.)

REV:00 STATUS: CHRON NO. 216478 DATE: 12/5/95

PREPARED BY: Guy H. DeBoo Guy H. DeBoo DATE: 12/5/95

REVISION SUMMARY: Initial Issue

DO ANY ASSUMPTIONS IN THIS CALCULATION REQUIRE LATER VERIFICATION
☐ YES ☒ NO

REVIEWED BY: V. K. Verma V. K. Verma DATE: 12/5/95

REVIEW METHOD: Detailed Review COMMENTS (C OR NC): NC

APPROVED BY: Steven C. Hunsader DATE: 12/5/95

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CALCULATION REVISION PAGE

CALCULATION NO. NED-P-MSD-086 PAGE NO.: 2

REV: STATUS: CHRON NO. DATE:

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DO ANY ASSUMPTIONS IN THIS CALCULATION REQUIRE LATER VERIFICATION
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1.0 Purpose/Objective:

This calculation determines the critical crack size and its projected leakage for the Main Steam (MS) line outside the containment building of the LaSalle Nuclear Station. The piping being evaluated is downstream of the outboard isolation valves in the steam tunnel. These quantities are being calculated to determine the maximum possible leak rate, prior to line rupture, for the MS line during normal operation. This maximum leak rate is needed to support the leakage detection requirement of 10CFR50 Appendix A General Design Criteria 54.

2.0 Methodology and Acceptance Criteria:

The critical crack size is calculated using a limit load methodology. This approach is used because the normal operating temperature of the MS line is 550°F which is significantly greater than the minimum upper shelf temperature (defined as 200°F by Reference 1) for A155 Gr KC70 carbon steel piping material. At this temperature the piping material possesses significant ductility and sufficient toughness to justify a plastic collapse failure mechanism. Test results for the carbon steel pipe tests documented in References 3 and 4 show the failure loads are greater than the loads predicted by limit load methodology when 2.4 Sm is used as the definition of the flow stress. Since this line is not subject to aging mechanisms known to embrittle the piping material, this approach remains valid for the operating life of the MS line. Experience has shown that circumferentially oriented flaws produce the limiting critical crack length and associated leak rate. This is because the operating loads and pressure contribute to the crack opening and flaw instability for a circumferential flaw where only the pressure load contributes to crack opening and instability for the axially oriented flaws. This evaluation determines the critical crack size and leak rate for a circumferentially oriented throughwall flaw using a limit load approach. This methodology has also been validated by GE for this application in Reference 7. The limit load methodology defined in the ASME Boiler & Pressure Vessel Code, Section XI, 1989 Edition, Reference 1, is used as guidance for this calculation. The specific equations used to determine the allowable bending moment for the critical crack size is provided in Section 6.0 of this calculation. Attachment A summarizes the piping axial forces and bending moments for the subject piping. This evaluation uses the maximum operating bending moment and is listed in Section 4.0 of this calculation. A limit load evaluation uses the material flow stress to determine the limiting bending moment which would cause plastic collapse. The material flow stress for this calculation is defined as 2.4 S_m at the operating temperature and is listed in Section 4.0.

To calculate the leak rate from the critical crack size, the PICEP program, Reference 2, developed by EPRI is used. This program uses an elastic plastic estimation scheme to calculate the crack opening displacement of the circumferential throughwall flaw under combined tension and bending loads. The leak rate calculation for steam through the crack is based on the steady state, single phase energy equation assuming isentropic flow. See Reference 2 for more details on the analytical approach and the validation for this approach

against test results. To calculate the crack opening displacement, the stress-strain relationship for the piping material is required. For this evaluation, the piping test results reported in Reference 3 for an A155 CK70 28" pipe with a 0.930" wall at 550°F, Pipe ID# DP2-F26, Experiment # 4111-2 were used. The PICEP program requires a Ramberg-Osgood relation, presented below, to represent the stress-strain properties.

$$\frac{\varepsilon}{\varepsilon_0} = \frac{\sigma}{\sigma_0} + \alpha \cdot \left(\frac{\sigma}{\sigma_0}\right)^n$$ Ramberg-Osgood Stress-Strain Relation

Where ε_0 is a reference strain associated with the σ_0, reference stress, and α and n are the stress-strain curve fitting coefficient and exponent respectively. The values used in this calculation are presented in Section 4.0.

3.0 Assumptions:

The stress-strain properties of the 28", A155 CK70, test results from Reference 3 are assumed to represent the LaSalle Station MS piping because these are realistic stress-strain properties for the installed piping. Using Code minimum stress-strain properties may over predict the crack opening displacement, thus overpredicting the leak rate. Using realistic stress-strain properties will realistically predict the strain deformation during crack opening and provide a conservative estimate of the crack leak rate.

4.0 Design Inputs:

4.1 Piping geometrical data:

$t := 0.967 \cdot in$ Nominal pipe wall thickness, Attachment A.

$D := 26 \cdot in$ Pipe outside diameter, Attachment A.

$R := \frac{D - t}{2}$ $R = 12.516 \cdot in$ Mean pipe radius

$A := \pi \cdot \frac{D^2 - (D - 2 \cdot t)^2}{4}$ $A = 76.048 \cdot in^2$ Pipe cross-sectional area

$Z := \frac{\pi \cdot \left[D^4 - (D - 2 \cdot t)^4\right]}{32 \cdot D}$ $Z = 458.912 \cdot in^3$ Section Modulus

Defining the units for this calculation $kip = 1000 \cdot lbf$ $ksi = 1000 \cdot psi$

4.2 Material Properties:

The following material properties used for the critical crack size calculations were obtained from Reference 5 for the MS line material:

$S_m := 19.6 \cdot ksi$ material stress limit at operating temperature, 550°F

$\sigma_f := 2.4 \cdot S_m$ $\sigma_f = 47.04 \cdot ksi$ material flow stress at operating temperature

For the leak rate calculations, the following Ramberg-Osgood Relation coefficient and strain hardening exponent are used.

$\alpha := 1.107$ $n := 5.55$

The reference stress and strain values for this evaluation are:

$\sigma_o := 33.5 \cdot ksi$ $\varepsilon_o := 0.00129$

These parameters are taken from References 3 and 8.

4.3 Operating Loads:

$P_d := 1025.0 \cdot psi$ Operating Pressure, Attachment A.

$P_p := P_d \cdot \pi \cdot \left(\frac{D}{2} - t\right)^2$ $P_p = 4.663 \cdot 10^5 \cdot lbf$ Axial force due to pressure

$P := P_p + 0.0 \cdot lbf$ total axial load on pipe, including pressure from piping analysis results provided in Attachment A.

$M := 3.64 \cdot 10^3 \cdot in \cdot kip$ applied moment at the maximum bending moment location from piping analysis results provided in Attachment A.

4.4 Applied Membrane and Bending Stress Values:

$P_m := \frac{P}{A}$

$P_m = 6.131 \cdot 10^3 \cdot psi$ primary membrane stress in the pipe from piping analysis

$P_b := \frac{M}{Z}$ $P_b = 7.932 \cdot 10^3 \cdot psi$ primary bending stress in the pipe

5.0 References:

1. ASME Boiler & Pressure Vessel Code, Section XI, 1989 Edition.
2. PICEP, Pipe Crack Evaluation Program, Revision , EPRI NP-3596-SR, December 1987.
3. "Degraded Piping Program - Phase II", NUREG/CR-4082 Volume 8, March 1989
4. "Degraded Piping Program - Phase II", NUREG/CR-4082 Volume 7, March 1989
5. ASME Boiler & Pressure Vessel Code, Section III, Appendix I, 1977 Edition.
6. "Ductile Fracture Handbook", Volume 2, EPRI , October, 1990
7. "LaSalle Leak Detection Temperature Measurement", GENE Report DRF-E31-00029-3C, November 1995
8. USNRC PIFRAC Database Version 3.0, Battelle, N. Ghadiali.

6.0 Calculations:

6.1 Circumferential Flaw Critical Crack Size:

Allowable plastic collapse bending stress is calculated using the following relationship:

For a throughwall flaw $a := t$ and $\frac{a}{t} = 1$

Critical flaw half length is $l := 16.6 \cdot in$

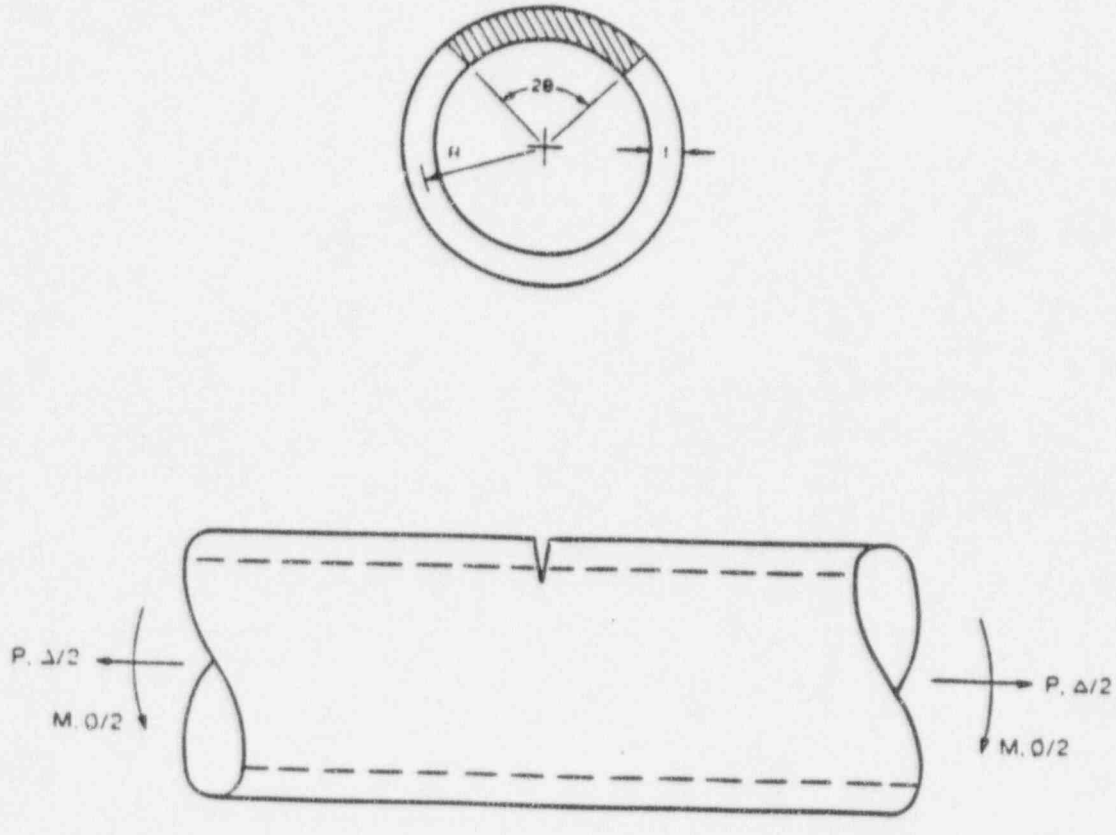
$\theta := \frac{l}{R}$ $\theta = 1.326 \cdot rad$ is the crack half angle per Figure 1

$\beta := \frac{1}{2} \cdot \left[\pi - \left(\frac{a}{t} \cdot \theta \right) - \pi \cdot \left(\frac{P_m}{\sigma_f} \right) \right]$ $\beta = 0.703$ $\theta + \beta = 2.029$ sum is less than π, therefore this formulation is acceptable.

$P_{ab} := \frac{2 \cdot (\sigma_f)}{\pi} \cdot \left(2 \cdot \sin(\beta) - \frac{a}{t} \cdot \sin(\theta) \right)$

The allowable bending stress of $P_{ab} = 9.663 \cdot ksi$ is greater than the applied bending bending stress of $P_b = 7.932 \cdot ksi$ The total critical crack length is $2 \cdot l = 33.2 \cdot in$

Figure 1 Through Wall Circumferential Flaw Model



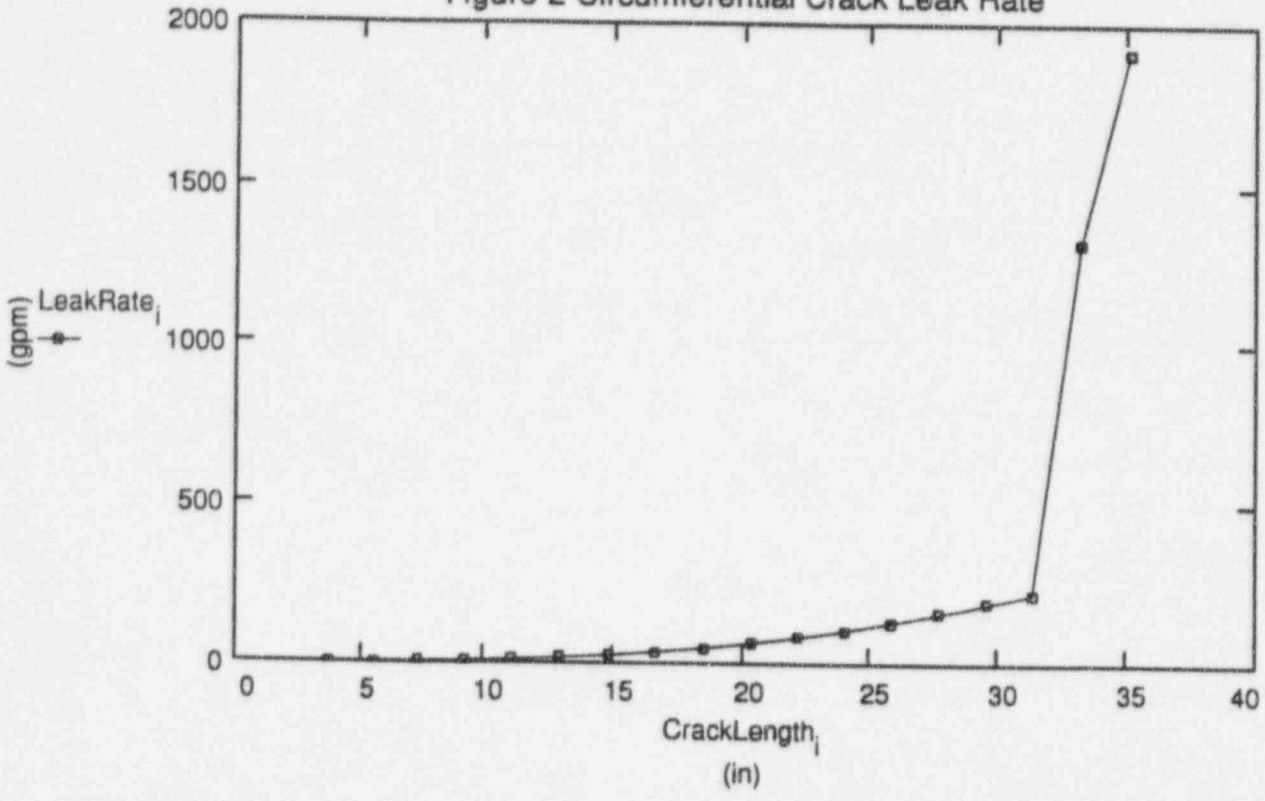
6.2 Circumferential Crack Leak Rate Calculations:

The leak rate calculations, performed using the PICEP program, are documented in Attachment B. The following results are taken from Attachment B are plotted below.

CrackLength :=	LeakRate :=
1.8462	0.0806
3.6924	0.5322
5.5386	1.5923
7.3847	3.4748
9.2309	6.4096
11.0771	10.6622
12.9233	16.5385
14.7695	24.3743
16.6157	34.5146
18.4618	47.2868
20.3080	63.0126
22.1542	81.9598
24.0004	104.2811
25.8466	129.9586
27.6928	158.6531
29.5389	189.2890
31.3851	219.0546
33.2313	1312.3144
35.0775	1908.5948

i := 1 .. 18

Figure 2 Circumferential Crack Leak Rate



The leak rate prior to a crack length of approximately 32" is choked. Once the flaw length reaches this limit and the flow through the crack in no longer choked, the leak rate increases significantly.

Using a cubic spline interpolation method, the leak rate for the critical crack length of x := 33.2 inches is:

cubic := cspline(CrackLength, LeakRate)

Interpolated_Leak_Rate := interp(cubic, CrackLength, LeakRate, x)

Interpolated_Leak_Rate = 1291.31 gpm

7.0 Summary and Conclusions:

The critical crack length for a circumferential throughwall flaw in the MS line in the steam tunnel has been calculated to be 33.2" long. The leak rate for a circumferentail flaw of this length is approximately 1290 gpm.

Attachment A:

The attached tables provide the axial forces and bending moments at all the analytical model node points of the main steam piping in the steam tunnel. The forces and moments are based on the Unit 2 stress analyses because the Unit 1 stress reports refer to the Unit 2 analyses. The following references to Sargent & Lundy piping stress reports were used to obtain this information.

Subsystem Name	Stress Report No.
1MS05	EMD-065681, Rev 05
1MS06	EMD-065683, Rev 05
1MS07	EMD-065684, Rev 05
1MS08	EMD-065682, Rev 05
2MS05	EMD-065380, Rev 06
2MS06	EMD-065381, Rev 06
2MS07	EMD-065382, Rev 06
2MS08	EMD-065383, Rev 06

Subsystem 2MS05
Operating Pressure 1025 psi
Operating Temperature 550 ° F.
Pipe OD 26"
Pipe Wall Thickness 0.967"
Pipe Section Modulus, Z= 458.912

Element Number	Node Number	Load Type	F_A (Lbs)	M_B (Ft-Lbs)	M_C (Ft-Lbs)	Stress (psi)	Total Stress (psi)
1	5	WT	-354.00	1865.00	29735.00	779.06	1366.51
		TH	8445.00	3436.00	1279.00	95.87	
		FC	9884.00	19716.00	14717.00	643.34	
		TR	5621.00	2726.00	1190.00	77.78	
	15	WT	332.00	1942.00	36242.00	949.04	2061.83
		TH	-8445.00	3265.00	17529.00	466.25	
		FC	9884.00	22699.00	19844.00	788.39	
		TR	5621.00	3017.00	1490.00	87.99	
5	23	WT	-147.00	-4883.00	2718.00	146.13	1793.17
		TH	8441.00	-8422.00	-32044.00	866.37	
		FC	5784.00	42612.00	8987.00	1138.76	
		TR	744.00	6325.00	3666.00	191.16	
	25	WT	143.00	5513.00	-14634.00	408.92	1890.25
		TH	-8441.00	9531.00	35165.00	952.70	
		FC	5784.00	49150.00	10971.00	1316.84	
		TR	744.00	7041.00	4120.00	213.32	
6	27	WT	-287.00	-5769.00	13070.00	373.58	1840.65
		TH	8788.00	-9936.00	-22284.00	638.00	
		FC	5684.00	51896.00	8104.00	1373.46	
		TR	743.00	7345.00	2660.00	204.27	
	30	WT	282.00	5128.00	-9219.00	275.85	1805.37
		TH	-8788.00	11795.00	-16092.00	521.72	
		FC	5684.00	44170.00	6098.00	1165.95	
		TR	743.00	4925.00	1686.00	136.12	
9	32	WT	-265.00	-3416.00	2065.00	104.38	4156.35
		TH	8730.00	-16812.00	118510.00	3129.92	
		FC	5560.00	26712.00	28042.00	1012.70	
		TR	742.00	6783.00	13265.00	389.58	
	33	WT	261.00	2883.00	-759.00	77.96	5128.19
		TH	-8730.00	18361.00	-150513.00	3964.91	
		FC	5560.00	23449.00	35555.00	1113.71	
		TR	742.00	8096.00	16884.00	489.63	
11	35A	WT	-270.00	14.00	2442.00	63.86	5961.18
		TH	8558.00	176994.00	19614.00	4656.51	
		FC	5415.00	41785.00	22102.00	1236.06	
		TR	776.00	19888.00	9179.00	572.76	
	35B	WT	140.00	2554.00	-839.00	70.30	5167.54
		TH	-7957.00	-175045.00	22134.00	4613.66	
		FC	8862.00	17314.00	21324.00	718.25	
		TR	8421.00	9942.00	10080.00	370.22	

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Element Number	Node Number	Load Type	F_A (Lbs)	M_B (Ft-Lbs)	M_C (Ft-Lbs)	Stress (psi)	Total Stress (psi)
14	37	WT	508.00	-1978.00	-138.00	51.85	4574.49
		TH	7956.00	155687.00	-19299.00	4102.19	
		FC	8040.00	14462.00	17576.00	595.17	
		TR	636.00	8770.00	7708.00	305.31	
	40	WT	-2917.00	-162.00	3765.00	98.54	3537.98
		TH	-7956.00	-83758.00	8765.00	2202.13	
		FC	8040.00	42462.00	33948.00	1421.56	
		TR	636.00	6175.00	6677.00	237.81	
16	42	WT	-13003.00	2483.00	-7700.00	211.56	2309.66
		TH	7957.00	5744.00	2659.00	165.51	
		FC	6270.00	60250.00	48425.00	2021.26	
		TR	467.00	7401.00	13193.00	395.56	
	43	WT	10170.00	-5001.00	11968.00	339.17	3645.57
		TH	-7957.00	78879.00	-15052.00	2099.81	
		FC	6270.00	54464.00	47241.00	1885.26	
		TR	467.00	8344.00	15906.00	469.68	
18	45A	WT	-6087.00	-18882.00	6800.00	524.78	5911.16
		TH	7957.00	165842.00	117950.00	5321.51	
		FC	4931.00	30728.00	13579.00	878.46	
		TR	316.00	3355.00	5798.00	175.16	
	45B	WT	479.00	3648.00	636.00	96.83	4912.34
		TH	-6890.00	-162389.00	7408.00	4250.69	
		FC	5530.00	27033.00	17716.00	845.15	
		TR	903.00	2159.00	7661.00	208.13	
20	50	WT	-481.00	-258.00	7869.00	205.88	3938.52
		TH	6803.00	6021.00	-138325.00	3620.46	
		FC	6721.00	15836.00	18456.00	635.91	
		TR	2638.00	3656.00	1824.00	106.84	
	60A	WT	481.00	-212.00	16946.00	443.15	3980.04
		TH	-6803.00	-26742.00	106599.00	2873.81	
		FC	6721.00	30158.00	16760.00	902.19	
		TR	2638.00	10221.00	1713.00	270.99	
22	60B	WT	-252.00	951.00	-20340.00	532.45	5437.76
		TH	8470.00	31874.00	-153794.00	4106.99	
		FC	7409.00	39060.00	19789.00	1144.97	
		TR	2214.00	15795.00	1440.00	414.73	
	62	WT	252.00	-5944.00	12541.00	362.90	4798.34
		TH	-8470.00	-17387.00	60780.00	1653.08	
		FC	7409.00	104086.00	46258.00	2978.40	
		TR	2214.00	50692.00	3010.00	1327.87	

Subsystem 2MS05
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Pipe Section Modulus, Z= 458.912

Element Number	Node Number	Load Type	F_A (Lbs)	M_B (Ft-Lbs)	M_C (Ft-Lbs)	Stress (psi)	Total Stress (psi)
23	63	WT	-252.00	5421.00	-4028.00	176.60	4111.85
		TH	8472.00	15858.00	-40904.00	1147.16	
		FC	8411.00	94922.00	47814.00	2779.21	
		TR	12766.00	46341.00	3157.00	1214.57	
	65	WT	252.00	-3627.00	-38645.00	1014.96	3691.16
		TH	-8472.00	-10609.00	-27296.00	765.77	
		FC	8411.00	66857.00	43906.00	2091.51	
		TR	12766.00	32430.00	2817.00	851.20	
A24	66	WT	-252.00	1218.00	-458.00	34.03	3671.33
		TH	8472.00	3563.00	118838.00	3108.87	
		FC	9722.00	31748.00	16422.00	934.66	
		TR	12863.00	12857.00	1457.00	338.35	
	68	WT	252.00	1153.00	2267.00	66.51	6445.24
		TH	-8472.00	3372.00	-208942.00	5464.29	
		FC	9722.00	21376.00	38119.00	1142.79	
		TR	12863.00	10321.00	2204.00	275.97	
25	75	WT	252.00	2931.00	-20258.00	535.24	10033.74
		TH	-8472.00	8573.00	-276521.00	7234.17	
		FC	10075.00	62987.00	78220.00	2626.07	
		TR	12894.00	28515.00	4813.00	756.18	
		WT				0.00	0.00
		TH				0.00	
		FC				0.00	
		TR				0.00	

Notes:

WT = Weight condition
TH = Thermal condition
FC = Faulted condition
TR = Transient condition
Stress = $12 \times \mathrm{Sqrt}(M_B^2 + M_C^2)/Z$
Total Stress = $12*\mathrm{SQRT}((\mathrm{ABS}(M_{BWT}+M_{BTH})+\mathrm{SQRT}(M_{FBC}^2+M_{BTR}^2))^2+(\mathrm{ABS}(M_{CWT}+M_{CTH})+\mathrm{SQRT}(M_{CFC}^2+M_{CTR}^2))^2)/Z$

Subsystem 2MS06
Operating Pressure 1025 psi
Operating Temperature 550 ° F.
Pipe OD 26"
Pipe Wall Thickness 0.967"
Pipe Section Modulus, Z= 458.912

Element Number	Node Number	Load Type	F_A (Lbs)	M_B (Ft-Lbs)	M_C (Ft-Lbs)	Stress (psi)	Total Stress (psi)
1	5	WT	-383.00	1867.00	31513.00	825.47	1562.01
		TH	8529.00	3411.00	3908.00	135.64	
		FC	9618.00	28395.00	13829.00	825.87	
		TR	5701.00	1465.00	1335.00	51.83	
	15	WT	364.00	2269.00	38362.00	1004.87	2227.99
		TH	-8529.00	4357.00	16970.00	458.14	
		FC	9618.00	35323.00	18726.00	1045.42	
		TR	5701.00	1791.00	1720.00	64.93	
5	23	WT	-213.00	-5120.00	4108.00	171.65	2231.89
		TH	8525.00	-9682.00	-31344.00	857.82	
		FC	5734.00	62333.00	8326.00	1644.41	
		TR	458.00	3438.00	3689.00	131.86	
	25	WT	209.00	5696.00	-16062.00	445.63	2388.15
		TH	-8525.00	10764.00	34263.00	939.11	
		FC	5734.00	69731.00	10962.00	1845.78	
		TR	458.00	3786.00	4108.00	146.08	
C6	26	WT	-323.00	-4780.00	11290.00	320.59	2141.79
		TH	8759.00	-12869.00	17184.00	561.38	
		FC	5644.00	56332.00	6278.00	1482.13	
		TR	457.00	2904.00	1763.00	88.83	
	32	WT	313.00	2955.00	-5146.00	155.17	4283.58
		TH	-8759.00	17030.00	-120050.00	3170.59	
		FC	5644.00	30702.00	27433.00	1076.61	
		TR	457.00	1838.00	13473.00	355.57	
8	35A	WT	-332.00	3673.00	1916.00	108.33	6055.37
		TH	8613.00	178590.00	19400.00	4697.39	
		FC	5485.00	40867.00	20117.00	1191.08	
		TR	482.00	20127.00	2077.00	529.09	
	35B	WT	1792.00	4058.00	-1431.00	112.52	5029.16
		TH	-8008.00	-176621.00	18664.00	4644.14	
		FC	9227.00	15983.00	11079.00	508.53	
		TR	8603.00	7487.00	1757.00	201.09	
B9	37	WT	-615.00	-2788.00	-466.00	73.91	4211.89
		TH	8008.00	141100.00	14339.00	3708.60	
		FC	8415.00	17486.00	21415.00	722.94	
		TR	679.00	7017.00	1202.00	186.16	
	40	WT	-1256.00	766.00	3487.00	93.35	3640.46
		TH	-8008.00	-84525.00	7452.00	2218.80	
		FC	8415.00	41690.00	48139.00	1665.21	
		TR	679.00	6883.00	3242.00	198.95	

Subsystem 2MS06
Operating Pressure 1025 psi
Operating Temperature 550 ° F.
Pipe OD 26"
Pipe Wall Thickness 0.967"
Pipe Section Modulus, Z= 458.912

Element Number	Node Number	Load Type	F_A (Lbs)	M_B (Ft-Lbs)	M_C (Ft-Lbs)	Stress (psi)	Total Stress (psi)
C10	42	WT	-13469.00	2050.00	-7695.00	208.23	2554.82
		TH	8007.00	5741.00	2139.00	160.20	
		FC	7223.00	60151.00	64145.00	2299.42	
		TR	578.00	6424.00	4794.00	209.60	
	B42	WT	12824.00	-2746.00	8736.00	239.46	2620.40
		TH	-8007.00	13753.00	-4512.00	378.48	
		FC	7223.00	61354.00	64565.00	2329.00	
		TR	578.00	6427.00	4896.00	211.27	
12	43	WT	-10632.00	5113.00	-12272.00	347.64	3710.70
		TH	8007.00	-79984.00	12574.00	2117.17	
		FC	6201.00	54929.00	56208.00	2055.06	
		TR	488.00	5589.00	4733.00	191.51	
	45A	WT	6566.00	-9506.00	18835.00	551.68	5779.11
		TH	-8007.00	202874.00	-27534.00	5353.55	
		FC	6201.00	24809.00	26101.00	941.63	
		TR	488.00	1759.00	2008.00	69.80	
14	45B	WT	-539.00	-74.00	3436.00	89.87	4846.11
		TH	6782.00	-5686.00	-158927.00	4158.41	
		FC	5863.00	8756.00	29208.00	797.33	
		TR	2559.00	1414.00	1725.00	58.32	
	50	WT	539.00	-133.00	5952.00	155.68	4481.34
		TH	-6782.00	-4590.00	143429.00	3752.42	
		FC	5863.00	10868.00	21249.00	624.09	
		TR	2559.00	1203.00	1158.00	43.66	
16	60A	WT	-539.00	511.00	-15617.00	408.58	4106.58
		TH	6782.00	23402.00	-115050.00	3070.03	
		FC	6570.00	27952.00	17441.00	861.52	
		TR	2717.00	3136.00	1513.00	91.05	
	60B	WT	305.00	-1269.00	20193.00	529.06	5589.55
		TH	-8551.00	-29151.00	162821.00	4325.27	
		FC	6618.00	39515.00	18730.00	1143.47	
		TR	1915.00	5767.00	1997.00	159.59	
A17	61	WT	-305.00	2879.00	-23741.00	625.35	5382.89
		TH	8554.00	25492.00	-134567.00	3581.35	
		FC	7214.00	54739.00	29417.00	1624.96	
		TR	12860.00	10864.00	2805.00	293.40	
	62	WT	305.00	-1960.00	5388.00	149.92	3284.29
		TH	-8554.00	-17351.00	46498.00	1297.76	
		FC	7214.00	47464.00	53840.00	1876.82	
		TR	12860.00	8633.00	4154.00	250.52	

Subsystem 2MS06
Operating Pressure 1025 psi
Operating Temperature 550 ° F.
Pipe OD 26"
Pipe Wall Thickness 0.967"
Pipe Section Modulus, Z= 458.912

Element Number	Node Number	Load Type	F_A (Lbs)	M_B (Ft-Lbs)	M_C (Ft-Lbs)	Stress (psi)	Total Stress (psi)
19	65	WT	-305.00	1207.00	35073.00	917.66	3286.83
		TH	8554.00	10689.00	25559.00	724.43	
		FC	8214.00	42392.00	52383.00	1762.10	
		TR	12950.00	6492.00	3492.00	192.76	
	68	WT	305.00	-246.00	1859.00	49.03	3605.48
		TH	-8554.00	-2177.00	-117632.00	3076.46	
		FC	8214.00	21344.00	19974.00	764.39	
		TR	12950.00	2324.00	1420.00	71.22	
21	69	WT	-305.00	-590.00	-3581.00	94.90	6003.98
		TH	8555.00	-5224.00	197695.00	5171.29	
		FC	8903.00	17142.00	34219.00	1000.78	
		TR	13026.00	2792.00	2641.00	100.49	
	75	WT	305.00	1426.00	-22968.00	601.74	10385.47
		TH	-8555.00	12626.00	-277759.00	7270.57	
		FC	8903.00	56869.00	89750.00	2778.32	
		TR	13026.00	8324.00	5954.00	267.61	

Notes:

WT = Weight condition
TH = Thermal condition
FC = Faulted condition
TR = Transient condition
Stress = $12 \times \mathrm{Sqrt}(M_B^2 + M_C^2)/Z$
Total Stress = $12*\mathrm{SQRT}((\mathrm{ABS}(M_{BWT}+M_{BTH})+\mathrm{SQRT}(M_{BFC}^2+M_{BTR}^2))^2+(\mathrm{ABS}(M_{CWT}+M_{CTH})+\mathrm{SQRT}(M_{CFC}^2+M_{CTR}^2))^2)/Z$

Subsystem 2MS07
Operating Pressure 1025 psi
Operating Temperature 550 ° F.
Pipe OD 26"
Pipe Wall Thickness 0.967"
Pipe Section Modulus, Z= 458.912

Member Number	Node Number	Load Type	F_A (Lbs)	M_B (Ft-Lbs)	M_C (Ft-Lbs)	Stress (psi)	Total Stress (psi)
1	5	WT	-176.00	-17.00	31176.00	815.22	4059.65
		TH	10738.00	-132287.00	6369.00	3463.15	
		FC	10782.00	14211.00	13746.00	517.00	
		TR	5720.00	61.00	1237.00	32.39	
	15	WT	159.00	7.00	37907.00	991.22	2742.33
		TH	-10738.00	54495.00	19020.00	1509.28	
		FC	10782.00	18183.00	18606.00	680.27	
		TR	5720.00	38.00	1589.00	41.56	
5	23	WT	12.00	0.00	5439.00	142.22	1167.08
		TH	10721.00	-1150.00	-36409.00	952.53	
		FC	7095.00	17508.00	8914.00	513.74	
		TR	469.00	38.00	3497.00	91.45	
	25	WT	-16.00	-1.00	-17533.00	458.47	1244.31
		TH	-10721.00	-9609.00	39978.00	1075.15	
		FC	7095.00	23152.00	11427.00	675.12	
		TR	469.00	53.00	3877.00	101.39	
6	27	WT	-145.00	1.00	10767.00	281.54	1076.37
		TH	9568.00	9156.00	14206.00	441.94	
		FC	6763.00	17461.00	6336.00	485.71	
		TR	459.00	44.00	1564.00	40.91	
	32	WT	132.00	-1.00	-629.00	16.45	4115.47
		TH	-9568.00	-8253.00	-122582.00	3212.63	
		FC	6763.00	18916.00	29281.00	911.54	
		TR	459.00	23.00	12436.00	325.19	
8	35A	WT	-103.00	-3233.00	-1.00	84.54	6117.31
		TH	9350.00	186563.00	-7720.00	4882.57	
		FC	6556.00	44238.00	26587.00	1349.61	
		TR	517.00	18841.00	10.00	492.67	
	35B	WT	-1847.00	-122.00	1.00	3.19	5386.42
		TH	-8606.00	-184134.00	6141.00	4817.56	
		FC	8644.00	14065.00	41701.00	1150.78	
		TR	8435.00	7839.00	7.00	204.98	
B10	38	WT	2152.00	239.00	-1.00	6.25	5026.61
		TH	8605.00	174163.00	-5898.00	4556.76	
		FC	7970.00	10293.00	37506.00	1017.00	
		TR	604.00	7717.00	7.00	201.79	
	40	WT	-4870.00	-1281.00	0.00	33.50	3687.13
		TH	-8605.00	-85283.00	3728.00	2232.18	
		FC	7970.00	53241.00	10312.00	1418.06	
		TR	604.00	7313.00	22.00	191.23	

Subsystem 2MS07
Operating Pressure 1025 psi
Operating Temperature 550 ° F.
Pipe OD 28"
Pipe Wall Thickness 0.967"
Pipe Section Modulus, Z= 458.912

Member Number	Node Number	Load Type	F_A (Lbs)	M_B (Ft-Lbs)	M_C (Ft-Lbs)	Stress (psi)	Total Stress (psi)
11	41	WT	-11019.00	2290.00	0.00	59.88	2177.73
		TH	8604.00	-804.00	-1627.00	47.46	
		FC	6344.00	76020.00	28031.00	2118.66	
		TR	408.00	6945.00	29.00	181.61	
	42	WT	8191.00	-3374.00	0.00	88.23	4215.70
		TH	-8604.00	93281.00	-631.00	2439.24	
		FC	6344.00	65790.00	40604.00	2021.59	
		TR	408.00	4592.00	24.00	120.08	
13	45A	WT	-4115.00	-4937.00	0.00	129.10	6566.46
		TH	8604.00	226633.00	-3886.00	5927.05	
		FC	5140.00	28008.00	22318.00	936.46	
		TR	285.00	1573.00	3.00	41.13	
	45B	WT	108.00	-5097.00	-1.00	133.28	6926.40
		TH	-9248.00	-228725.00	-6181.00	5983.07	
		FC	6162.00	28882.00	27064.00	1034.99	
		TR	511.00	2220.00	6.00	58.05	
15	50	WT	-108.00	1.00	-9179.00	240.02	6538.77
		TH	9251.00	5802.00	-214296.00	5605.64	
		FC	6640.00	19121.00	25256.00	828.33	
		TR	10915.00	6.00	2061.00	53.89	
	57	WT	108.00	-1.00	17709.00	463.07	5158.00
		TH	-9251.00	-3996.00	145468.00	3805.25	
		FC	6640.00	29286.00	31190.00	1118.76	
		TR	10915.00	10.00	1943.00	50.81	
22	58	WT	-108.00	0.00	-1730.00	45.24	4067.58
		TH	9251.00	1647.00	-55938.00	1463.35	
		FC	8159.00	105660.00	54893.00	3113.50	
		TR	10980.00	11.00	2478.00	64.80	
	60	WT	108.00	0.00	-34549.00	903.42	5374.05
		TH	-9251.00	293.00	-18001.00	470.77	
		FC	8159.00	173689.00	56801.00	4778.45	
		TR	10980.00	12.00	2314.00	60.51	
26	63	WT	-108.00	0.00	-1169.00	30.57	4256.54
		TH	9254.00	-161.00	99735.00	2607.95	
		FC	9351.00	97315.00	31763.00	2676.79	
		TR	11021.00	14.00	1607.00	42.02	
	65	WT	108.00	0.00	5419.00	141.70	4147.85
		TH	-9254.00	134.00	-116856.00	3055.65	
		FC	9351.00	81150.00	24742.00	2218.41	
		TR	11021.00	15.00	1353.00	35.38	

Subsystem 2MS07
Operating Pressure 1025 psi
Operating Temperature 550 ° F.
Pipe OD 28"
Pipe Wall Thickness 0.967"
Pipe Section Modulus, Z= 458.912

Member Number	Node Number	Load Type	F_A (Lbs)	M_B (Ft-Lbs)	M_C (Ft-Lbs)	Stress (psi)	Total Stress (psi)
30	67	WT	-108.00	0.00	-8034.00	210.08	6480.34
		TH	9253.00	25.00	215882.00	5645.06	
		FC	10175.00	15052.00	39487.00	1105.01	
		TR	11049.00	6.00	1578.00	41.26	
	75	WT	108.00	0.00	-14078.00	368.12	10519.14
		TH	-9253.00	-143.00	-289012.00	7557.32	
		FC	10175.00	86796.00	89603.00	3262.03	
		TR	11049.00	18.00	3792.00	99.16	

Notes:

WT = Weight condition
TH = Thermal condition
FC = Faulted condition
TR = Transient condition
Stress = $12 \times \mathrm{Sqrt}(M_B^2 + M_C^2)/Z$
Total Stress = $12*SQRT((ABS(M_{BWT}+M_{BTH})+SQRT(M_{BFC}^2+M_{BTR}^2))^2+(ABS(M_{CWT}+M_{CTH})+SQRT(M_{CFC}^2+M_{CTR}^2))^2)/Z$

Subsystem 2MS08
Operating Pressure 1025 psi
Operating Temperature 550 ° F.
Pipe OD 28"
Pipe Wall Thickness 0.967"
Pipe Section Modulus, Z= 458.912

Element Number	Node Number	Load Type	F_A (Lbs)	M_B (Ft-Lbs)	M_C (Ft-Lbs)	Stress (psi)	Total Stress (psi)
1	5	WT	-212.00	333.00	30[illegible]73.00	786.42	1837.51
		TH	8461.00	-35734.00	-1572.00	935.31	
		FC	9662.00	19697.00	14920.00	646.13	
		TR	5646.00	1981.00	1430.00	83.89	
	15	WT	190.00	469.00	36666.00	958.85	2180.08
		TH	-8461.00	20776.00	13974.00	654.72	
		FC	9662.00	22570.00	20139.00	790.97	
		TR	5646.00	2295.00	1790.00	76.11	
5	23	WT	-5.00	-1089.00	1704.00	52.88	1631.73
		TH	8457.00	-9198.00	-23541.00	660.89	
		FC	5731.00	43338.00	8738.00	1156.04	
		TR	749.00	4342.00	4227.00	158.46	
	25	WT	1.00	1221.00	-13494.00	354.29	1643.49
		TH	-8457.00	6722.00	25601.00	692.13	
		FC	5731.00	49900.00	10905.00	1335.82	
		TR	749.00	4956.00	4747.00	179.45	
6	27	WT	-119.00	-1275.00	12712.00	334.07	1581.39
		TH	8648.00	-5682.00	-12934.00	369.41	
		FC	5348.00	52652.00	7955.00	1392.41	
		TR	769.00	5216.00	2524.00	151.52	
	30	WT	114.00	1123.00	-10706.00	281.49	1874.18
		TH	-8648.00	8120.00	-26440.00	723.24	
		FC	5348.00	44678.00	8965.00	1191.56	
		TR	769.00	3822.00	4167.00	147.85	
9	32	WT	-99.00	-715.00	8471.00	222.29	4981.75
		TH	8582.00	-14699.00	131519.00	3460.48	
		FC	5227.00	27419.00	39840.00	1264.65	
		TR	769.00	5742.00	21998.00	594.49	
	33	WT	96.00	588.00	-8703.00	228.09	6120.23
		TH	-8582.00	16730.00	-164354.00	4319.87	
		FC	5227.00	24702.00	49925.00	1456.54	
		TR	769.00	6676.00	27568.00	741.71	
11	35A	WT	-137.00	5240.00	483.00	137.60	5957.69
		TH	8397.00	172350.00	18375.00	4532.29	
		FC	5075.00	41832.00	24053.00	1261.79	
		TR	808.00	19014.00	7464.00	534.13	
	35B	WT	1756.00	3015.00	-252.00	79.11	5188.87
		TH	-7879.00	-170671.00	28550.00	4524.85	
		FC	10623.00	21234.00	24235.00	842.55	
		TR	8729.00	9647.00	8221.00	331.43	

Subsystem 2MS08
Operating Pressure 1025 psi
Operating Temperature 550 ° F.
Pipe OD 28"
Pipe Wall Thickness 0.967"
Pipe Section Modulus, Z= 458.912

Element Number	Node Number	Load Type	F_A (Lbs)	M_B (Ft-Lbs)	M_C (Ft-Lbs)	Stress (psi)	Total Stress (psi)
14	37	WT	-1108.00	-2788.00	20.00	72.90	4583.95
		TH	7879.00	151679.00	-24832.00	4019.03	
		FC	9369.00	18362.00	19896.00	707.96	
		TR	693.00	8788.00	6276.00	282.38	
	40	WT	-1300.00	1942.00	844.00	55.37	3336.20
		TH	-7879.00	-81110.00	11018.00	2140.41	
		FC	9369.00	39648.00	32633.00	1342.75	
		TR	693.00	7125.00	4660.00	222.62	
16	42	WT	-9964.00	-1025.00	-1780.00	53.71	2090.85
		TH	7878.00	4571.00	3965.00	158.23	
		FC	6681.00	56414.00	49020.00	1954.26	
		TR	455.00	8655.00	9628.00	338.53	
	43	WT	7130.00	31.00	2797.00	73.14	3894.37
		TH	-7878.00	78452.00	-20217.00	2118.45	
		FC	6681.00	52818.00	50387.00	1908.79	
		TR	455.00	8375.00	11225.00	366.22	
18	45A	WT	-3047.00	-4004.00	2021.00	117.28	6201.73
		TH	7878.00	170931.00	109219.00	5304.16	
		FC	4764.00	32972.00	15462.00	952.27	
		TR	225.00	2461.00	4998.00	145.68	
	45B	WT	142.00	-2445.00	145.00	64.05	5261.80
		TH	-7020.00	-168142.00	8646.00	4402.52	
		FC	5461.00	28408.00	19518.00	901.27	
		TR	702.00	2306.00	6127.00	171.19	
A19	46	WT	-142.00	-143.00	-4416.00	115.53	4857.31
		TH	7030.00	-2008.00	-157070.00	4107.53	
		FC	5992.00	15628.00	23274.00	733.06	
		TR	2571.00	4309.00	2013.00	124.36	
	47	WT	142.00	141.00	5845.00	152.88	4487.78
		TH	-7030.00	-4737.00	145823.00	3815.11	
		FC	5992.00	13795.00	18848.00	610.76	
		TR	2571.00	3030.00	1790.00	92.02	
21	60A	WT	-142.00	-131.00	-5309.00	138.87	3737.17
		TH	7025.00	34224.00	-96667.00	2681.47	
		FC	7167.00	37282.00	20887.00	1117.45	
		TR	2663.00	10793.00	1617.00	285.37	
	60B	WT	99.00	-8.00	2081.00	54.42	4897.67
		TH	-8309.00	-38391.00	138335.00	3754.01	
		FC	6682.00	48070.00	24429.00	1409.98	
		TR	2159.00	15193.00	1710.00	399.79	

Subsystem 2MS08
Operating Pressure 1025 psi
Operating Temperature 550 ° F.
Pipe OD 28"
Pipe Wall Thickness 0.967"
Pipe Section Modulus, Z= 458.912

Element Number	Node Number	Load Type	F_A (Lbs)	M_B (Ft-Lbs)	M_C (Ft-Lbs)	Stress (psi)	Total Stress (psi)
A22	61	WT	-99.00	434.00	7514.00	196.81	4391.03
		TH	8309.00	31565.00	-105297.00	2874.44	
		FC	7163.00	66898.00	34967.00	1973.85	
		TR	12807.00	23131.00	1765.00	606.61	
	62	WT	99.00	-1107.00	-1619.00	51.29	4416.69
		TH	-8309.00	-20780.00	53120.00	1491.52	
		FC	7163.00	110193.00	45629.00	3118.68	
		TR	12807.00	37086.00	2014.00	971.18	
23	63	WT	-99.00	1034.00	3349.00	91.65	3985.83
		TH	8313.00	19414.00	-38668.00	1131.41	
		FC	7923.00	102752.00	46121.00	2945.09	
		TR	12857.00	34442.00	2097.00	902.28	
	65	WT	99.00	-704.00	-23204.00	607.04	3326.19
		TH	-8313.00	-13211.00	-26951.00	784.85	
		FC	7923.00	72089.00	39935.00	2154.96	
		TR	12857.00	23494.00	2280.00	617.23	
A24	66	WT	-99.00	241.00	-9931.00	259.76	3328.31
		TH	8314.00	4525.00	118836.00	3109.67	
		FC	9170.00	34415.00	11661.00	950.17	
		TR	12953.00	9922.00	1320.00	261.73	
	68	WT	99.00	208.00	5192.00	135.87	6418.50
		TH	-8314.00	3912.00	-208091.00	5442.29	
		FC	9170.00	21694.00	41056.00	1214.22	
		TR	12953.00	6999.00	1555.00	187.48	
25	75	WT	99.00	546.00	-22243.00	581.80	10060.94
		TH	-8314.00	10240.00	-275034.00	7196.79	
		FC	9538.00	65429.00	79134.00	2684.95	
		TR	12974.00	20113.00	3955.00	536.00	

Notes:

WT = Weight condition
TH = Thermal condition
FC = Faulted condition
TR = Transient condition
Stress = $12 \times \mathrm{Sqrt}(M_B^2 + M_C^2)/Z$
Total Stress = $12*\mathrm{SQRT}((\mathrm{ABS}(M_{BWT}+M_{BTH})+\mathrm{SQRT}(M_{BFC}^2+M_{BTR}^2))^2+(\mathrm{ABS}(M_{CWT}+M_{CTH})+\mathrm{SQRT}(M_{CFC}^2+M_{CTR}^2))^2)/Z$

RESEARCH PROGRAMS

THE SUBJECT COMPUTER PROGRAM HAS BEEN CLASSIFIED BY EPRI AS A RESEARCH PROGRAM. AS SUCH, IT HAS NOT BEEN DEVELOPED AND TESTED TO THE EXTENT THAT A PRODUCTION PROGRAM WOULD BE, AND UNFORSEEN RESULTS MAY OCCUR WHEN RUNNING THE PROGRAM. EPRI DOES NOT MAKE ANY WARRANTY OR REPRESENTATION WHATSOEVER, EXPRESS OR IMPLIED, INCLUDING ANY WARRANTY OF MERCHANTABILITY OR FITNESS OF ANY PURPOSE WITH RESPECT TO THE PROGRAM; NOR DOES EPRI ASSUME ANY LIABILITY WHATSOEVER WITH RESPECT TO ANY USE OF THE PROGRAM OR ANY PORTION THEREOF OR WITH RESPECT TO ANY DAMAGES WHICH MAY RESULT FROM SUCH USE.

P I C E P V E R S I O N 06/30/87

PIPE CRACK EVALUATION PROGRAM
EPRI REPORT NP-3569-SR REV.1 BY D.M. NORRIS AND V.K. CHEXAL

UNITS:BRITISH,LENGTH-INCHES,MASS-LBM,TEMP-DEGF
NEW-STYLE PICEP INPUT AS PER EPRI REPORT NP-3569-REV.1

ECHO PRINT OF INPUT DATA

LaSalle Station MS Line Leak Rate for Circumferential Flaw

MODE	IPLAS	ISOL
0	2	2

DO	THICK
26.0000	.9670

IFDIR	IFAREA	NDIV	COD	AF
0	1	20	.0000E+00	.0000E+00

YOUNG	S0	E0	ALPHA	FACN	FSR	Z	SF
.260D+08	.335D+05	.000D+00	.111D+01	.555D+01	.562D+05	.000D+00	.000D+00

IN	PRES	T0	PB	TRACT	BMOM	PMSTR	PBSTR
4	1039.7	1.00	14.7	0.	3640000.	0.	0.

EK	AR	N90	N45	CD	FFRED
.20000D-03	1.000	0	0	.000	.0000

END OF ECHO PRINT

CRITICAL CRACK LENGTH (NO CORRECTION FACTORS) 36.92

PIPE DATA

PIPE OUTSIDE DIAMETER	= .2600D+02
PIPE THICKNESS	= .9670D+00

CRACK DATA

CRACK SHAPE	= ELLIPTICAL
CRACK ORIENTATION	= CIRCUMFERENTIAL
CRACK SURFACE ROUGHNESS	= .2000D-03
HALF CRACK LENGTH INCREMENT	= .9231D+00
NUMBER OF INCREMENTS	= 20
NUMBER OF 45 DEG TURNS	= 0
NUMBER OF 90 DEG TURNS	= 0
EXIT TO INLET AREA RATIO	= 1.00

MATERIAL DATA

YOUNG'S MODULUS		= .260D+08
YIELD STRESS		= .335D+05
RAMBERG-OSGOOD	EXPONENT	= .555D+01
RAMBERG-OSGOOD	CONSTANT	= .111D+01
FLOW STRESS		= .562D+05
YIELD STRAIN		= .129D-02
REFERENCE STRESS		= .335D+05
REFERENCE STRAIN		= .129D-02

LOAD DATA

AXIAL (NON-PRESSURE) LOAD	=	.000D+00
TOTAL BENDING MOMENT	=	.364D+07
TOTAL AXIAL STRESS	=	.613D+04
TOTAL BENDING STRESS	=	.764D+04

FLUID DATA

PRESSURE	=	.104D+04
TEMPERATURE	=	.100D+01
ENTRANCE LOSS COEFFICENT	=	.610D+00
FRICTION FACTOR	=	.134D-01
BACK PRESSURE	=	.147D+02

OUTPUT DATA

LaSalle Station MS Line Leak Rate for Circumferential Flaw

CRITICAL CRACK LENGTH (Z=1) 36.9237
SUBCOOLING = .0

	CRACK LENGTH INCHES	COD INCHES	FL/D	LEAK FLOW RATE GPM @ 200 F	CHOKED
1	1.8462	.001934	26.0	.0806	YES
2	3.6924	.004209	8.4	.5322	YES
3	5.5386	.006875	4.2	1.5923	YES
4	7.3847	.010017	2.5	3.4748	YES
5	9.2309	.013761	1.7	6.4096	YES
6	11.0771	.018276	1.1	10.6622	YES
7	12.9233	.023784	.8	16.5385	YES
8	14.7695	.030571	.6	24.3743	YES
9	16.6157	.039003	.4	34.5146	YES
10	18.4618	.049552	.3	47.2868	YES
11	20.3080	.062838	.2	63.0126	YES
12	22.1542	.079693	.2	81.9598	YES
13	24.0004	.101269	.1	104.2811	YES
14	25.8466	.129211	.1	129.9586	YES
15	27.6928	.165965	.1	158.6531	YES
16	29.5389	.215310	.0	189.2890	YES
17	31.3851	.283309	.0	219.0546	YES
18	33.2313	.379987	.0	1312.3144	NO
19	35.0775	.522233	.0	1908.5948	NO
20	36.9237	.738271	.0	2845.6603	NO

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